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Energy, environment and sustainable development

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Abstract

Globally, buildings are responsible for approximately 40% of the total world annual energy consumption. Most of this energy is for the provision of lighting, heating, cooling, and air conditioning. Increasing awareness of the environmental impact of CO_2 and NO_x emissions and CFCs triggered a renewed interest in environmentally friendly cooling, and heating technologies. Under the 1997 Montreal Protocol, governments agreed to phase out chemicals used as refrigerants that have the potential to destroy stratospheric ozone. It was therefore considered desirable to reduce energy consumption and decrease the rate of depletion of world energy reserves and pollution of the environment. One way of reducing building energy consumption is to design building, which are more economical in their use of energy for heating, lighting, cooling, ventilation and hot water supply. Passive measures, particularly natural or hybrid ventilation rather than air-conditioning, can dramatically reduce primary energy consumption. However, exploitation of renewable energy in buildings and agricultural greenhouses can, also, significantly contribute towards reducing dependency on fossil fuels. Therefore, promoting innovative renewable applications and reinforcing the renewable energy market will contribute to preservation of the ecosystem by reducing emissions at local and global levels. This will also contribute to the amelioration of environmental conditions by replacing conventional fuels with renewable energies that produce no air pollution or greenhouse gases. The provision of good indoor environmental quality while achieving energy and cost-efficient operation of the heating, ventilating and air-conditioning (HVAC) plants in buildings represents a multi-variant problem. The comfort of building occupants is dependent on many environmental parameters including air speed, temperature, relative humidity and quality in addition to lighting and noise. The overall objective is to provide a high level of building performance (BP), which can be defined as indoor environmental quality (IEQ), energy efficiency (EE) and cost efficiency (CE).

- Indoor environmental quality is the perceived condition of comfort that building occupants experience due to the physical and psychological conditions to which they are exposed by their

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surroundings. The main physical parameters affecting IEQ are air speed, temperature, relative humidity and quality.
- Energy efficiency is related to the provision of the desired environmental conditions while consuming the minimal quantity of energy.
- Cost efficiency is the financial expenditure on energy relative to the level of environmental comfort and productivity that the building occupants attained. The overall cost efficiency can be improved by improving the indoor environmental quality and the energy efficiency of a building.

This article discusses the potential for such integrated systems in the stationary and portable power market in response to the critical need for a cleaner energy technology. Anticipated patterns of future energy use and consequent environmental impacts (acid precipitation, ozone depletion and the greenhouse effect or global warming) are comprehensively discussed in this paper. Throughout the theme several issues relating to renewable energies, environment and sustainable development are examined from both current and future perspectives.

Keywords: Energy; Environment; Sustainable development; Global warming

Contents

1. Introduction

Several definitions of sustainable development have been put forth, including the following common one: development that meets the needs of the present without compromising the ability of future generations to meet their own needs. A recent World Energy Council (WEC) study found that without any change in our current practice, the world energy demand in 2020 would be 50–80% higher than 1990 levels. According to a

recent USA Department of Energy (DoE) report, annual energy demand will increase from a current capacity of 363 million kilowatts to 750 million kilowatts by 2020. The world's energy consumption today is estimated to 22 billion $\mathrm{kWh\,yr^{-1}}$, 53 billion kWh by 2020. Such ever-increasing demand could place significant strain on the current energy infrastructure and potentially damage world environmental health by CO, CO_2, SO_2, NO_x effluent gas emissions and global warming. Achieving solutions to environmental problems that we face today requires long-term potential actions for sustainable development. In this regard, renewable energy resources appear to be the one of the most efficient and effective solutions since the intimate relationship between renewable energy and sustainable development. More rational use of energy is an important bridge to help transition from today's fossil fuel dominated world to a world powered by non-polluting fuels and advanced technologies such as photovoltaic (PV) and fuel cells (FC) [1].

An approach is needed to integrate renewable energies in a way to meet high building performance. However, because renewable energy sources are stochastic and geographically diffuse, their ability to match demand is determined by adoption of one of the following two approaches [2]: the utilisation of a capture area greater than that occupied by the community to be supplied, or the reduction of the community's energy demands to a level commensurate with the locally available renewable resources.

For a northern European climate, which is characterised by an average annual solar irradiance of $150\,\mathrm{W\,m^{-2}}$, the mean power production from a photovoltaic component of 13% conversion efficiency is approximately $20\,\mathrm{W\,m^{-2}}$. For an average wind speed of $5\,\mathrm{m\,s^{-1}}$, the power produced by a micro wind turbine will be of a similar order of magnitude, though with a different profile shape. In the UK, for example, a typical office building will have a demand in the order of $300\,\mathrm{kWh\,m^{-2}\,yr^{-1}}$. This translates into approximately $50\,\mathrm{W\,m^{-2}}$ of façade, which is twice as much as the available renewable energies [3]. Thus, the aim is to utilise energy efficiency measures in order to reduce the overall energy consumption and adjust the demand profiles to be met by renewable energies. For instance, this approach can be applied to greenhouses, which use solar energy to provide indoor environmental quality. The greenhouse effect is one result of the differing properties of heat radiation when it is generated at different temperatures. Objects inside the greenhouse, or any other building, such as plants, re-radiate the heat or absorb it. Because the objects inside the greenhouse are at a lower temperature than the sun, the re-radiated heat is of longer wavelengths, and cannot penetrate the glass. This re-radiated heat is trapped and causes the temperature inside the greenhouse to rise. Note that the atmosphere surrounding the earth, also, behaves as a large greenhouse around the world. Changes to the gases in the atmosphere, such as increased carbon dioxide content from the burning of fossil fuels, can act like a layer of glass and reduce the quantity of heat that the planet earth would otherwise radiate back into space. This particular greenhouse effect, therefore, contributes to global warming. The application of greenhouses for plants growth can be considered one of the measures in the success of solving this problem. Maximising the efficiency gained from a greenhouse can be achieved using various approaches, employing different techniques that could be applied at the design, construction and operational stages. The development of greenhouses could be a solution to farming industry and food security.

Energy security, economic growth and environment protection are the national energy policy drivers of any country of the world. As world populations grow, many faster than the average 2%, the need for more and more energy is exacerbated (Fig. 1). Enhanced

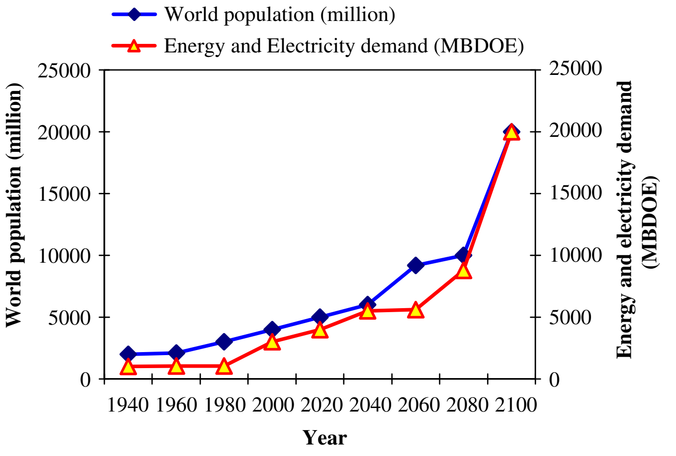

Fig. 1. Annual and estimated world population and energy demand. Million of barrels per day of oil equivalent (MBDOE).

lifestyle and energy demand rise together and the wealthy industrialised economics, which contain 25% of the world's population, consume 75% of the world's energy supply. The world's energy consumption today is estimated to 22 billion kWh yr^{-1}. About 6.6 billion metric tons carbon equivalent of greenhouse gas (GHG) emission are released in the atmosphere to meet this energy demand [4]. Approximately, 80% is due to carbon emissions from the combustion of energy fuels. At the current rate of usage, taking into consideration population increases and higher consumption of energy by developing countries, oil resources, natural gas and uranium will be depleted within a few decades. As for coal, it may take two centuries or so.

Technological progress has dramatically changed the world in a variety of ways. It has, however, also led to developments, e.g., environmental problems, which threaten man and nature. Build-up of carbon dioxide and other GHGs is leading to global warming with unpredictable but potentially catastrophic consequences. When fossil fuels burn, they emit toxic pollutants that damage the environment and people's health with over 700,000 deaths resulting each year, according to the World Bank review of 2000. At the current rate of usage, taking into consideration population increases and higher consumption of energy by developing countries, oil resources, natural gas and uranium will be depleted within a few decades, as shown in Figs. 2 and 3. As for coal, it may take two centuries or so. One must therefore endeavour to take precautions today for a viable world for coming generations.

Research into future alternatives has been and still being conducted aiming to solve the complex problems of this recent time, e.g., rising energy requirements of a rapidly and constantly growing world population and global environmental pollution. Therefore, options for a long-term and environmentally friendly energy supply have to be developed leading to the use of renewable sources (water, sun, wind, biomass, geothermal, hydrogen) and fuel cells. Renewables could shield a nation from the negative effect in the energy supply, price and related environment concerns. Hydrogen for fuel cells and the sun for PV have been considered for many years as a likely and eventual substitute for oil, gas, coal and uranium. They are the most abundant elements in the universe. The use of solar energy

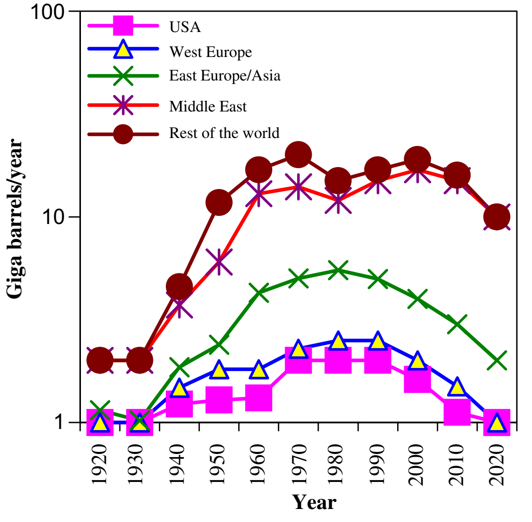

Fig. 2. World oil productions in the next 10–20 years.

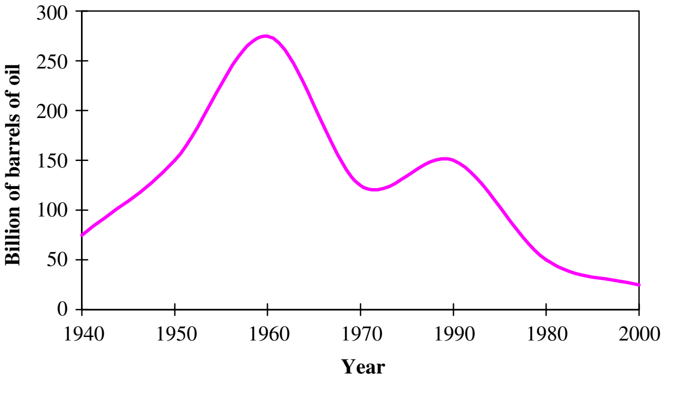

Fig. 3. Volume of oil discovered worldwide.

or PVs for the everyday electricity needs has distinct advantages: avoids consuming resources and degrading the environment through polluting emissions, oil spills and toxic by-products. A 1-kW PV system producing 150 kWh each month prevents 75 kg of fossil fuel from being mined. It avoids 150 kg of CO_2 from entering the atmosphere and keeps 473 l of water from being consumed. Electricity from fuel cells can be used in the same way as grid power: to run appliances and light bulbs and even to power cars since each gallon of gasoline produced and used in an internal combustion engine releases roughly 12 kg of CO_2, a GHS that contributes to global warming.

2. People, power and pollution

Over millions of years ago, plants covered the earth, converting the energy of sunlight into living tissue, some of which was buried in the depths of the earth to produce deposits

of coal, oil and natural gas. The past few decades, however, have experienced many valuable uses for these complex chemical substances, manufacturing from them plastics, textiles, fertiliser and the various end products of the petrochemical industry. Indeed, each decade sees increasing uses for these products. Renewable energy is the term used to describe a wide range of naturally occurring, replenishing energy sources. Coal, oil and gas, which will certainly be of great value to future generations, as they are to ours, are non-renewable natural resources. The rapid depletion of non-renewable fossil resources need not continue. This is particularly true now as it is, or soon will be, technically and economically feasible to supply all of man's needs from the most abundant energy source of all, the sun. The sunlight is not only inexhaustible, but, moreover, it is the only energy source, which is completely non-polluting.

Industry's use of fossil fuels has been blamed for warming the climate. When coal, gas and oil are burnt, they release harmful gases, which trap heat in the atmosphere and cause global warming. However, there has been an ongoing debate on this subject, as scientists have struggled to distinguish between changes, which are human induced, and those, which could be put down to natural climate variability. Nevertheless, industrialised countries have the highest emission levels, and must shoulder the greatest responsibility for global warming. However, action must also be taken by developing countries to avoid future increases in emission levels as their economies develop and populations grows, as clearly captured by the Kyoto Protocol [4]. Notably, human activities that emit carbon dioxide (CO_2), the most significant contributor to potential climate change, occur primarily from fossil fuel production. Consequently, efforts to control CO_2 emissions could have serious, negative consequences for economic growth, employment, investment, trade and the standard of living of individuals everywhere.

Scientifically, it is difficult to predict the relationship between global temperature and GHG concentrations. The climate system contains many processes that will change if warming occurs. Critical processes include heat transfer by winds and tides, the hydrological cycle involving evaporation, precipitation, runoff and groundwater and the formation of clouds, snow, and ice, all of which display enormous natural variability.

The equipment and infrastructure for energy supply and use are designed with long lifetimes, and the premature turnover of capital stock involves significant costs. Economic benefits occur if capital stock is replaced with more efficient equipment in step with its normal replacement cycle. Likewise, if opportunities to reduce future emissions are taken in a timely manner, they should be less costly. Such a flexible approach would allow society to take account of evolving scientific and technological knowledge, while gaining experience in designing policies to address climate change [4].

The World Summit on Sustainable Development in Johannesburg in 2002 committed itself to "encourage and promote the development of renewable energy sources to accelerate the shift towards sustainable consumption and production". Accordingly, it aimed at breaking the link between resource use and productivity. This can be achieved by the following:

- Trying to ensure economic growth does not cause environmental pollution.
- Improving resource efficiency.
- Examining the whole life-cycle of a product.
- Enabling consumers to receive more information on products and services.
- Examining how taxes, voluntary agreements, subsidies, regulation and information campaigns, can best stimulate innovation and investment to provide cleaner technology.

The energy conservation scenarios include rational use of energy policies in all economy sectors and the use of combined heat and power systems, which are able to add to energy savings from the autonomous power plants. Electricity from renewable energy sources is by definition the environmental green product. Hence, a renewable energy certificate system, as recommended by the World Summit, is an essential basis for all policy systems, independent of the renewable energy support scheme. It is, therefore, important that all parties involved support the renewable energy certificate system in place if it is to work as planned. Moreover, existing renewable energy technologies (RETs) could play a significant mitigating role, but the economic and political climate will have to change first. Climate change is real. It is happening now, and GHGs produced by human activities are significantly contributing to it. The predicted global temperature increase of between 1.5 and 4.5 °C could lead to potentially catastrophic environmental impacts [5]. These include sea level rise, increased frequency of extreme weather events, floods, droughts, disease migration from various places and possible stalling of the Gulf Stream. This has led scientists to argue that climate change issues are not ones that politicians can afford to ignore, and policy makers tend to agree [5]. However, reaching international agreements on climate change policies is no trivial task as the difficulty in ratifying the Kyoto Protocol has proved.

Therefore, the use of renewable energy sources and the rational use of energy, in general, are the fundamental inputs for any responsible energy policy. However, the energy sector is encountering difficulties because increased production and consumption levels entail higher levels of pollution and eventually climate change, with possibly disastrous consequences. At the same time, it is important to secure energy at an acceptable cost in order to avoid negative impacts on economic growth. To date, renewable energy contributes as much as 20% of the global energy supplies worldwide [5]. Over two-thirds of this come from biomass use, mostly in developing countries, some of it unsustainable. Yet, the potential for energy from sustainable technologies is huge. On the technological side, renewables have an obvious role to play. In general, there is no problem in terms of the technical potential of renewables to deliver energy. Moreover, there are very good opportunities for RETs to play an important role in reducing emissions of GHGs into the atmosphere, certainly far more than have been exploited so far. However, there are still some technical issues to address in order to cope with the intermittency of some renewables, particularly wind and solar. Yet, the biggest problem with relying on renewables to deliver the necessary cuts in GHG emissions is more to do with politics and policy issues than with technical ones [5]. For example, the single most important step governments could take to promote and increase the use of renewables is to improve access for renewables to the energy market. This access to the market needs to be under favourable conditions and, possibly, under favourable economic rates as well. One move that could help, or at least justify, better market access would be to acknowledge that there are environmental costs associated with other energy supply options and that these costs are not currently internalised within the market price of electricity or fuels. This could make a significant difference, particularly if appropriate subsidies were applied to renewable energy in recognition of the environmental benefits it offers. Similarly, cutting energy consumption through end-use efficiency is absolutely essential. This suggests that issues of end-use consumption of energy will have to come into the discussion in the foreseeable future [6].

However, RETs have the benefit of being environmentally benign when developed in a sensitive and appropriate way with the full involvement of local communities. In addition, they are diverse, secure, locally based and abundant. In spite of the enormous potential and the multiple benefits, the contribution from renewable energy still lags behind the ambitious claims for it due to the initially high development costs, concerns about local impacts, lack of research funding and poor institutional and economic arrangements [7].

Hence, an approach is needed to integrate renewable energies in a way that meets high building performance requirements. However, because renewable energy sources are stochastic and geographically diffuse, their ability to match demand is determined by adoption of one of the following two approaches [8]: the utilisation of a capture area greater than that occupied by the community to be supplied, or the reduction of the community's energy demands to a level commensurate with the locally available renewable resources.

2.1. Energy and population growth

Urban areas throughout the world have increased in size during recent decades. About 50% of the world's population and approximately 7.6% in more developed countries are urban dwellers [9]. Even though there is evidence to suggest that in many 'advanced' industrialised countries there has been a reversal in the rural-to-urban shift of populations, virtually all population growth expected between 2000 and 2030 will be concentrated in urban areas of the world. With an expected annual growth of 1.8%, the world's urban population will double in 38 years [9].

With increasing urbanisation in the world, cities are growing in number, population and complexity. At present, 2% of the world's land surface is covered by cities, yet the people living in them consume 75% of the resources consumed by mankind [10]. Indeed, the ecological footprint of cities is many times larger than the areas they physically occupy. Economic and social imperatives often dictate that cities must become more concentrated, making it necessary to increase the density to accommodate the people, to reduce the cost of public services, and to achieve required social cohesiveness. The reality of modern urbanisation inevitably leads to higher densities than in traditional settlements and this trend is particularly notable in developing countries.

Generally, the world population is rising rapidly, notably in the developing countries. Historical trends suggest that increased annual energy use per capita, which promotes a decrease in population growth rate, is a good surrogate for the standard of living factors. If these trends continue, the stabilisation of the world's population will require the increased use of all sources of energy, particularly as cheap oil and gas are depleted. The improved efficiency of energy use and renewable energy sources will, therefore, be essential in stabilising population, while providing a decent standard of living all over the world [10]. Moreover, energy is the vital input for economic and social development of any country. With an increase in industrial and agricultural activities, the demand for energy is also rising. It is, however, a well-accepted fact that commercial energy use has to be minimised. This is because of the environmental effects and the availability problems. Consequently, the focus has now shifted to non-commercial energy resources, which are renewable in nature. This is bound to have less environmental effects and also the availability is guaranteed. However, even though the ideal situation will be to enthuse people to use renewable energy resources, there are many practical difficulties, which need to be tackled.

The people groups who are using the non-commercial energy resources, like urban communities, are now becoming more demanding and wish to have commercial energy resources made available for their use. This is attributed to the increased awareness, improved literacy level and changing culture [10]. The quality of life practiced by people is usually represented as being proportional to the per capita energy use of that particular country. It is not surprising that people want to improve their quality of life. Consequently, it is expected that the demand for commercial energy resources will increase at a greater rate in the years to come [10]. Because of this emerging situation, the policy makers are left with two options: either to concentrate on renewable energy resources and have them as substitutes for commercial energy resources or to have a dual approach in which renewable energy resources will contribute to meet a significant portion of the demand whereas the conventional commercial energy resources would be used with caution whenever necessary. Even though the first option is the ideal one, the second approach will be more appropriate for a smooth transition [10].

2.2. *Energy and environmental problems*

Technological progress has dramatically changed the world in a variety of ways. It has, however, also led to developments of environmental problems, which threaten man and nature. During the past two decades, the risk and reality of environmental degradation have become more apparent. Growing evidence of environmental problems is due to a combination of several factors since the environmental impact of human activities has grown dramatically because of the sheer increase of world population, consumption, industrial activity, etc. throughout the 1970s most environmental analysis and legal control instruments concentrated on conventional effluent gas pollutants such as SO_2, NO_x, CO_2, particulates, and CO (Table 1). Recently, environmental concerns have extended to the control of micro or hazardous air pollutants, which are usually toxic chemical substances and harmful in small doses, as well to that of globally significant pollutants such as CO_2.

Table 1
EU criteria pollutant standards in the ambient air environment

Pollutant	EU limit
CO	$30\,mg\,m^{-2}$; 1 h
NO_2	$200\,\mu g\,m^{-2}$; 1 h
O_3	$235\,\mu g\,m^{-2}$; 1 h
SO_2	$250–350\,\mu g\,m^{-2}$; 24 h $80–120\,\mu g\,m^{-2}$; annual
PM_{10}	$250\,\mu g\,m^{-2}$; 24 h $80\,\mu g\,m^{-2}$; annual
$SO_2 + PM_{10}$	$100–150\,\mu g\,m^{-2}$; 24 h $40–60\,\mu g\,m^{-2}$; annual
Pb	$2\,\mu g\,m^{-2}$; annual
Total suspended particulate (TSP)	$260\,\mu g\,m^{-2}$; 24 h
HC	$160\,\mu g\,m^{-2}$; 3 h

Aside from advances in environmental science, developments in industrial processes and structures have led to new environmental problems. For example, in the energy sector, major shifts to the road transport of industrial goods and to individual travel by cars has led to an increase in road traffic and hence a shift in attention paid to the effects and sources of NO_x and volatile organic compound (VOC) emissions. Environmental problems span a continuously growing range of pollutants, hazards and ecosystem degradation over wider areas. The main areas of environmental problems are: major environmental accidents, water pollution, maritime pollution, land use and sitting impact, radiation and radioactivity, solid waste disposal, hazardous air pollutants, ambient air quality, acid rain, stratospheric ozone depletion and global warming (greenhouse effect, global climatic change) (Table 2).

The four more important types of harm from man's activities are global warming gases, ozone destroying gases, gaseous pollutants and microbiological hazards (Table 3). The earth is some 30 °C warmer due to the presence of gases but the global temperature is rising. This could lead to the sea level rising at the rate of 60 mm each decade with the growing risk of flooding in low-lying areas (Fig. 4). At the United Nations Earth Summit at Rio in June 1992, some 153 countries agreed to pursue sustainable development [11]. A main aim was to reduce emission of carbon dioxide and other GHGs. Reduction of energy use in buildings is a major role in achieving this. Carbon dioxide targets are proposed to encourage designers to look at low energy designs and energy sources.

Table 2
Significant EU environmental directives in water, air and land environments

Environment	Directive name
Water	Surface water for drinking
	Sampling surface water for drinking
	Drinking water quality
	Quality of freshwater supporting fish
	Shellfish waters
	Bathing waters
	Dangerous substances in water
	Groundwater
	Urban wastewater
	Nitrates from agricultural sources
Air	Smokes in air
	Sulphur dioxide in air
	Lead in air
	Large combustion plants
	Existing municipal incineration plants
	New municipal incineration plants
	Asbestos in air
	Sulphur content of gas oil
	Lead in petrol
	Emissions from petrol engines
	Air quality standards for NO_2
	Emissions from diesel engines
Land	Protection of soil when sludge is applied

Table 3
The external environment

Damage	Manifestation	Design
NO_x, SO_x	Irritant	Low NO_x burners
	Acid rain land damage	Low sulphur fuel
	Acid rain fish damage	Sulphur removal
	Global warming	Thermal insulation
CO_2	Rising sea level	Heat recovery
	Drought, storms	Heat pumps
O_3 destruction	Increased ultra violet	No CFC's or HCFC's
	Skin cancer	Minimum air conditioning
	Crop damage	Refrigerant collection
Legionnellosis	Pontiac fever	Careful maintenance
	Legionnaires	Dry cooling towers

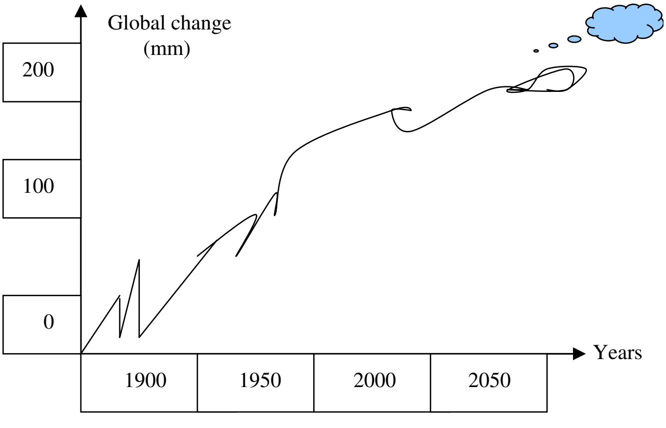

Fig. 4. Change in global sea level.

Problems with energy supply and use are related not only to global warming that is taking place, due to effluent gas emission mainly CO_2, but also to such environmental concerns as air pollution, acid precipitation, ozone depletion, forest destruction and emission of radioactive substances. These issues must be taken into consideration simultaneously if humanity is to achieve a bright energy future with minimal environmental impacts. Much evidence exists, which suggests that the future will be negatively impacted if humans keep degrading the environment (Table 4).

During the past century, global surface temperatures have increased at a rate near 0.6 °C/century and the average temperature of the Atlantic, Pacific and Indian oceans (covering 72% of the earth surface) have risen by 0.06 °C since 1995. Global temperatures in 2001 were 0.52 °C above the long-term 1880–2000 average (the 1880–2000 annually averaged combined land and ocean temperature is 13.9 °C). Also, according to the USA Department of Energy, world emissions of carbon are expected to increase by 54% above 1990 levels by 2015 making the earth likely to warm 1.7–4.9 °C over the period 1990–2100,

Table 4
Global emissions of the top fourteen nations by total CO_2 volume (billion of tons)

Rank	Nation	CO_2	Rank	Nation	CO_2	Rank	Nation	CO_2
1	USA	1.36	6	India	0.19	11	Mexico	0.09
2	Russia	0.98	7	UK	0.16	12	Poland	0.08
3	China	0.69	8	Canada	0.11	13	S. Africa	0.08
4	Japan	0.30	9	Italy	0.11	14	S. Korea	0.07

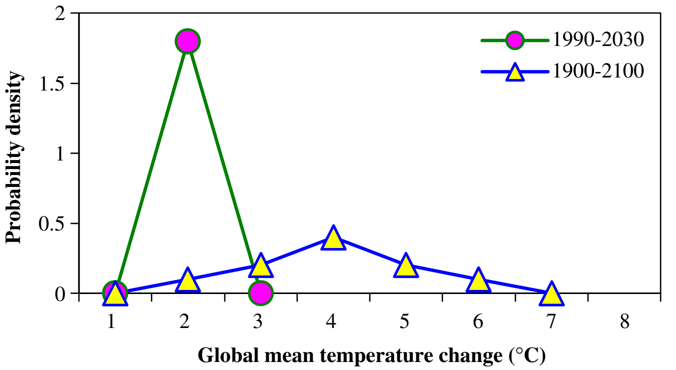

Fig. 5. Global mean temperature changes over the period of 1990–2100 and 1990–2030.

as shown in Fig. 5. Such observation and others demonstrate that interests will likely increase regarding energy related environment concerns and that energy is one of the main factors that must be considered in discussions of sustainable development.

2.3. Environmental transformations

In recent years, a number of countries have adopted policies aimed at giving a greater role to private ownership in the natural resource sector. For example, in the UK, the regional water companies have been privatised and have been given a considerable degree of control over the exploitation of the nation's regional water resources. Similar policies have been followed in France and other European countries. Typically, a whole range of new regulatory instruments such as technological standards accompanies such privatisation on water treatment plants, minimum standards on drinking water quality, price controls and maximum withdrawal quotas. While some of these instruments address problems of monopolistic behaviour and other forms of imperfect competition, the bulk of regulatory measures are concerned with establishing 'good practices' aimed at maintaining the quality of the newly privatised resources as a shorthand. Society has to meet the freshwater demands of its population and its industry by extracting water from the regional water resources that are provided by the natural environment (lakes, rivers, aquifers, etc.). These water resources are renewable but potentially destructible resources. While moderate amounts of human water extractions from a given regional water system can be sustained for indefinite periods, excessive extractions will change the geographical

and climatic conditions supporting the water cycle and will diminish the regenerative capacity of the regional water system, thereby reducing the potential for future withdrawals. Typically, recovery from any such resource degradation will be very slow and difficult, if not impossible; resource degradation is partially irreversible [12].

To make sustainable water extraction economically viable, the sustainable policy has to break even (all costs are covered by revenues) while unsustainable policy has to be unprofitable (costs exceed revenues):

$$(1+r)vt_{-1} = 5y_t + v_t, \tag{1}$$

where r is the interest rate, t the year, y is the revenue,

$$(1+r)vt_{-1} > 105y_t, \tag{2}$$

$$(1+r)vt_{-1} < \left[\frac{105}{105-5}\right]v_t. \tag{3}$$

The term [105/(105−5)] is to define the natural productivity factor of the water resource as $(1+g) = [105/(105-5)]$; g is the natural productivity rate.

Rate g will be close to zero if the sustainable extraction level is much smaller than the unsustainable level. Using g, the equation can be as follows:

$$v_t > \frac{1+r}{1+g}v_{t-1}. \tag{4}$$

Regulatory measures that prevent resource owners from adopting certain unsustainable extraction policies are a necessary pre-condition for the effective operation of a privatised natural resource sector. Unregulated water privatisation would result in an inflationary dynamics whose distributional effects would threaten the long-term viability of the economy. This inflationary dynamics is not due to any form of market imperfection but is a natural consequence of the competitive arbitrage behaviour of unregulated private resource owners.

3. Sustainability concept

Absolute sustainability of electricity supply is a simple concept: no depletion of world resources and no ongoing accumulation of residues. Relative sustainability is a useful concept in comparing the sustainability of two or more generation technologies. Therefore, only renewables are absolutely sustainable, and nuclear is more sustainable than fossil. However, any discussion about sustainability must not neglect the ability or otherwise of the new technologies to support the satisfactory operation of the electricity supply infrastructure. The electricity supply system has been developed to have a high degree of resilience against the loss of transmission circuits and major generators, as well as unusually large and rapid load changes. It is unlikely that consumers would tolerate any reduction in the quality of the service, even if this were the result of the adoption of otherwise benign generation technologies. Renewables are generally weather dependent and as such their likely output can be predicted but not controlled. The only control possible is to reduce the output below that available from the resource at any given time. Therefore, to safeguard system stability and security, renewables must be used in

conjunction with other, controllable, generation and with large-scale energy storage. There is a substantial cost associated with this provision.

It is useful to codify all aspects of sustainability, thus ensuring that all factors are taken into account for each and every development proposal. Therefore, with the intention of promoting debate, the following considerations are proposed:

(1) Long-term availability of the energy source or fuel.
(2) Price stability of energy source or fuel.
(3) Acceptability or otherwise of by-products of the generation process.
(4) Grid services, particularly controllability of real and reactive power output.
(5) Technological stability, likelihood of rapid technical obsolescence.
(6) Knowledge base of applying the technology.
(7) Life of the installation—a dam may last more than 100 years, but a gas turbine probably will not.
(8) Maintenance requirement of the plant.

3.1. Environmental aspects

Environmental pollution is a major problem facing all nations of the world. People have caused air pollution since they learned how to use fire, but man-made air pollution anthropogenic air pollution has rapidly increased since industrialisation began. Many volatile organic compounds and trace metals are emitted into the atmosphere by human activities. The pollutants emitted into the atmosphere do not remain confined to the area near the source of emission or to the local environment, and can be transported over long distances, and create regional and global environmental problems. The privatisation, and price liberalisation in energy fields has to be secured (but not fully). Availability and adequate energy supplies to the major productive sector is needed. The result is that, the present situation of energy supplies is far better than 10 years ago (Table 5).

Table 5
Classifications of data requirements

	Plant data	System data
Existing data	Size	Peak load
	Life	Load shape
	Cost (fixed and var. O&M)	Capital costs
	Forced outage	Fuel costs
	Maintenance	Depreciation
	Efficiency	Rate of return
	Fuel	Taxes
	Emissions	
Future data	All of above, plus	System lead growth
	Capital costs	Fuel price growth
	Construction trajectory	Fuel import limits
	Date in service	Inflation

A great challenge facing the global community today is to make the industrial economy more like the biosphere, that is, to make it a more closed system. This would save energy, reduce waste and pollution, and reduce costs. In short, it would enhance sustainability. Often, it is technically feasible to recycle waste in one of several different ways. For some wastes, there are powerful arguments for incineration with energy recovery, rather than material recycling. Cleaner production approach and pollution control measures are needed in the recycling sector as much as in another. The industrial sector world widely is responsible for about one-third of anthropogenic emissions of carbon dioxide, the most important greenhouse gas. Industry is also an important emitter of several other greenhouse gases. And many of industry's products emit greenhouse gases as well, either during use or after they become waste. Opportunities exist for substantial reducing industrial emissions through more efficient production and use of energy: fuel substitutions, the use of alternative energy technologies, process modification, and by revising materials strategies to make use of less energy and greenhouse gas intensive materials. Industry has an additional role to play through the design of products that use less energy and materials and produce lower greenhouse gas emissions.

Development in the environmental sense is a rather recent concern relating to the need to manage scarce natural resources in a prudent manner because human welfare ultimately depends on ecological services. The environmental interpretation of sustainability focuses on the overall viability and health of ecological systems—defined in terms of a comprehensive, multiscale, dynamic, hierarchical measure of resilience, vigour and organisation. Natural resource degradation, pollution and loss of biodiversity are detrimental because they increase vulnerability, undermine system health, and reduce resilience. The environmental issues include:

- Global and transnational (climate change, ozone layer depletion).
- Natural habitats (forests and other ecosystems).
- Land (agricultural zones).
- Water resources (river basin, aquifer, water shed).
- Urban-industrial (metropolitan area, air-shed).

Environmental sustainability depends on several factors, including:

- Climate change (magnitude and frequency of shocks).
- Systems vulnerability (extent of impact damage).
- System resilience (ability to recover from impacts).

Economic importance of environmental issue is increasing, and new technologies are expected to reduce pollution derived both from productive processes and products, with costs that are still unknown. This is due to market uncertainty, weak appropriability regime, lack of a dominant design, and difficulties in reconfiguring organisational routines. The degradation of the global environment is one of the most serious energy issues. Various options are proposed and investigated to mitigate climate change, acid rain or other environmental problems. Additionally, the following aspects play a fundamental role in developing environmental technologies, pointing out how

technological trajectories depend both on exogenous market conditions and endogenous firm competencies:

(1) Regulations concerning introduction of zero emission vehicles (ZEV), create market demand and business development for new technologies.
(2) Each stage of technology development requires alternative forms of division and coordination of innovative labour, upstream and downstream industries are involved in new forms of inter-firm relationships, causing a reconfiguration of product architectures and reducing effects of path dependency.
(3) Product differentiation increases firm capabilities to plan at the same time technology reduction and customer selection, while meeting requirements concerning network externalities.
(4) It is necessary to find and/or create alternative funding sources for each research, development and design stage of the new technologies.

Action areas for producers:

- *Management and measurement tools*—adopting environmental management systems appropriate for the business.
- *Performance assessment tools*—making use of benchmarking to identify scope for impact reduction and greater eco-efficiency in all aspects of the business.
- *Best practice tools*—making use of free help and advice from government best practice programmes (energy efficiency, environmental technology, resource savings).
- *Innovation and ecodesign*—rethinking the delivery of 'value added' by the business, so that impact reduction and resource efficiency are firmly built in at the design stage.
- *Cleaner, leaner production processes*—pursuing improvements and savings in waste minimisation, energy and water consumption, transport and distribution, as well as reduced emissions. Tables 6–8 indicate energy conservation, sustainable development and environment.
- *Supply chain management*—specifying more demanding standards of sustainability from 'upstream' suppliers, while supporting smaller firms to meet those higher standards.

Table 6
Classification of key variables defining facility sustainability

Criteria	Intra-system impacts	Extra-system impacts
Stakeholder satisfaction	Standard expectations met Relative importance of standard expectations	Covered by attending to extra-system resource base and ecosystem impacts
Resource base impacts	Change in intra-system resource bases Significance of change	Resource flow into/out of facility system Unit impact exerted by flow on source/sink system Significance of unit impact
Ecosystem impacts	Change in intra-system ecosystems Significance of change	Resource flows into/out of facility system Unit impact exerted by how on source/sink system Significance of unit impact

Table 7
Energy and sustainable environment

Technological criteria	Energy and environment criteria	Social and economic criteria
Primary energy saving in regional scale	Sustainability according to greenhouse gas pollutant emissions	Labour impact
Technical maturity, reliability	Sustainable according to other pollutant emissions	Market maturity
Consistence of installation and maintenance requirements with local technical known-how	Land requirement	Compatibility with political, legislative and administrative situation
Continuity and predictability of performance	Sustainability according to other environmental impacts	Cost of saved primary energy

Table 8
Positive impact of durability, adaptability and energy conservation on economic, social and environment systems

Economic system	Social system	Environmental system
Durability	Preservation of cultural values	Preservation of resources
Meeting changing needs of economic development	Meeting changing needs of individuals and society	Reuse, recycling and preservation of resources
Energy conservation and saving	Savings directed to meet other social needs	Preservation of resources, reduction of pollution and global warming

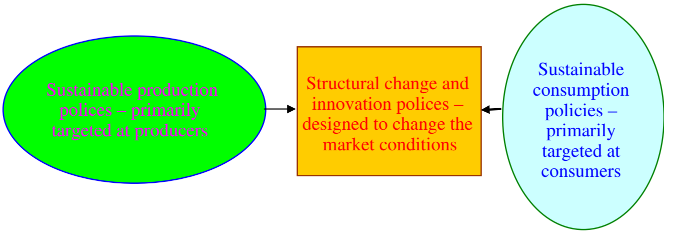

Fig. 6. Link between resources and productivity.

- *Product stewardship*—taking the broadest view of 'producer responsibility' and working to reduce all the 'downstream' effects of products after they have been sold on to customers.
- *Openness and transparency*—publicly reporting on environmental performance against meaningful targets; actively using clear labels and declarations so that customers are fully informed; building stakeholder confidence by communicating sustainability aims to the workforce, the shareholders and the local community (Fig. 6).

With the debate on climate change, the preference for real measured data has been changed. The analyses of climate scenarios need an hourly weather data series that allow for realistic changes in various weather parameters. By adapting parameters

in a proper way, data series can be generated for the site. Weather generators should be useful for:

- calculation of energy consumption (no extreme conditions are required),
- design purposes (extremes are essential), and
- predicting the effect of climate change such as increasing annually average of temperature.

This results in the following requirements:

- Relevant climate variables should be generated (solar radiation: global, diffuse, direct solar direction, temperature, humidity, wind speed and direction) according to the statistics of the real climate.
- The average behaviour should be in accordance with the real climate.
- Extremes should occur in the generated series in the way it will happen in a real warm period. This means that the generated series should be long enough to assure these extremes, and series based on average values from nearby stations.

Growing concerns about social and environmental sustainability have led to increased interest in planning for the energy utility sector because of its large resource requirements and production of emissions. A number of conflicting trends combine to make the energy sector a major concern, even though a clear definition of how to measure progress toward sustainability is lacking. These trends include imminent competition in the electricity industry, global climate change, expected long-term growth in population and pressure to balance living standards (including per capital energy consumption). Designing and implementing a sustainable energy sector will be a key element of defining and creating a sustainable society. In the electricity industry, the question of strategic planning for sustainability seems to conflict with the shorter time horizons associated with market forces as deregulation replaces vertical integration. Sustainable low-carbon energy scenarios for the new century emphasise the untapped potential of renewable resources. Rural areas can benefit from this transition. The increased availability of reliable and efficient energy services stimulates new development alternatives. It is concluded that renewable environmentally friendly energy must be encouraged, promoted, implemented, and demonstrated by full-scale plant especially for use in remote rural areas.

This is the step in a long journey to encourage a progressive economy, which continues to provide us with high living standards, but at the same time helps reduce pollution, waste mountains, other environmental degradation, and environmental rationale for future policy-making and intervention to improve market mechanisms. This vision will be accomplished by:

- 'Decoupling' economic growth and environmental degradation. The basket of indicators illustrated shows the progress being made (Table 9). Decoupling air and water pollution from growth, making good headway with CO_2 emissions from energy, and transport. The environmental impact of our own individual behaviour is more closely linked to consumption expenditure than the economy as a whole.
- Focusing policy on the most important environmental impacts associated with the use of particular resources, rather than on the total level of all resource use.

Table 9
The basket of indicators for sustainable consumption and production

Economy-wide decoupling indicators
1. Greenhouse gas emissions
2. Air pollution
3. Water pollution (river water quality)
4. Commercial and industrial waste arisings and household waste not cycled
Resource use indicators
5. Material use
6. Water abstraction
7. Homes built on land not previously developed, and number of households
Decoupling indicators for specific sectors
8. Emissions from electricity generation
9. Motor vehicle kilometres and related emissions
10. Agricultural output, fertiliser use, methane emissions and farmland bird populations
11. Manufacturing output, energy consumption and related emissions
12. Household consumption, expenditure energy, water consumption and waste generated

- Increasing the productivity of material and energy use that are economically efficient by encouraging patterns of supply and demand, which are more efficient in the use of natural resources. The aim is to promote innovation and competitiveness. Investment in areas like energy efficiency, water efficiency and waste minimisation.
- Encouraging and enabling active and informed individual and corporate consumers.

On some climate change issues (such as global warming), there is no disagreement among the scientists. The greenhouse effect is unquestionably real; it is essential for life on earth. Water vapour is the most important GHG; next is carbon dioxide (CO_2). Without a natural greenhouse effect, scientists estimate that the earth's average temperature would be $-18\,^{\circ}C$ instead of its present $14\,^{\circ}C$. There is also no scientific debate over the fact that human activity has increased the concentration of the GHGs in the atmosphere (specially CO_2 from combustion of coal, oil and gas). The greenhouse effect is also being amplified by increased concentrations of other gases, such as methane, nitrous oxide, and CFCs as a result of human emissions. Most scientists predict that rising global temperatures will raise the sea level and increase the frequency of intense rain or snowstorms. Climate change scenarios sources of uncertainty, and factors influencing the future climate are:

- The future emission rates of the GHGs.
- The effect of this increase in concentration on the energy balance of the atmosphere.
- The effect of these emissions on GHGs concentrations in the atmosphere.
- The effect of this change in energy balance on global and regional climate.

3.2. Wastes

Waste is defined as an unwanted material that is being discarded. Waste includes items being taken for further use, recycling or reclamation. Waste produced at household,

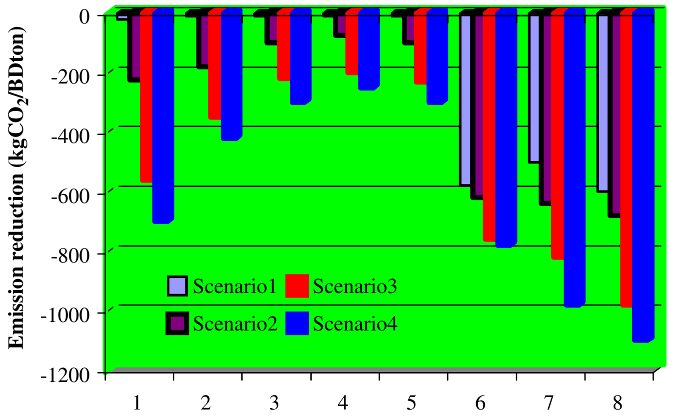

Fig. 7. Comparison of thermal biomass usage options, CHP displacing natural gas as a heat source: (1) large steam power (LSP); (2) small steam power (SSP); (3) Brayton cycle power (BCP); (4) bio-oil conversion power (B-CP); (5) gasification power (GP); (6) small steam CHP (SSCHP); (7) turboden cycle CHP (TCCHP); (8) entropic cycle CHP (ECCHP).

commercial and industrial premises are control waste and come under the waste regulations. Waste Incineration Directive (WID) emissions limit values will favour efficient, inherently cleaner technologies that do not rely heavily on abatement. For existing plant, the requirements are likely to lead to improved control of:

- NO_x emissions, by the adoption of in-furnace combustion control and abatement techniques.
- Acid gases, by the adoption of abatement techniques and optimisation of their control.
- Particulate control techniques, and their optimisation, e.g., of bag filters and electrostatic precipitators.

The waste and resources action programme has been working hard to reduce demand for virgin aggregates and market uptake of recycled and secondary alternatives (Fig. 7). The programme targets are:

- to deliver training and information on the role of recycling and secondary aggregates in sustainable construction for influences in the supply chain, and
- to develop a promotional programme to highlight the new information on websites.

Lifecycle analysis of several ethanol feedstocks shows the emission displacement per ton of feedstock is highest for corn stover and switchgrass (about 0.65 tons of CO_2 per ton of feedstock) and lowest for corn (about 0.5 ton).

Emissions due to cultivation and harvesting of corn and wheat are higher than those for lignocellulosics, and although the latter have a far higher process energy requirement (Fig. 8). GHG emissions are lower because this energy is produced from biomass residue, which is carbon neutral.

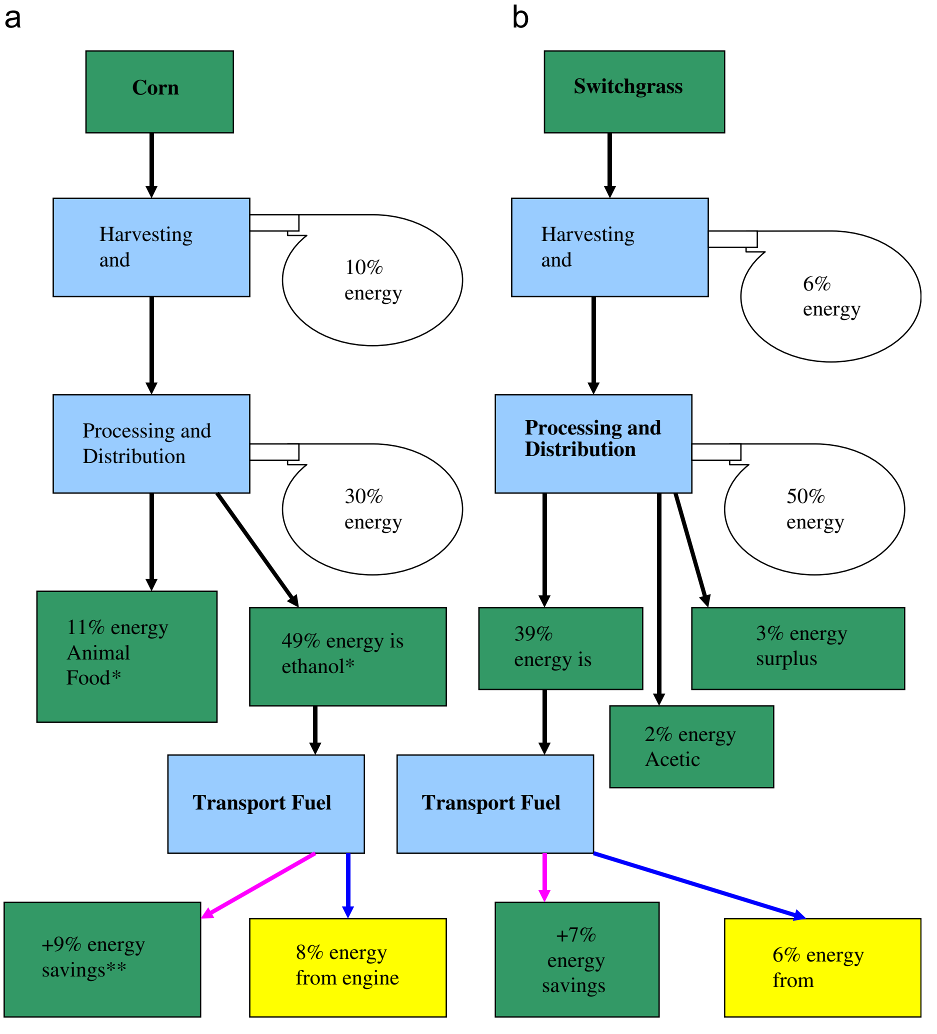

Fig. 8. The lifecycle energy balance of corn and Switchgrass reveal a paradox: corn, as an ethanol feedstock requires less energy for production, i.e., more of the original energy in starch is retained in the ethanol fuel. Nevertheless, the Switchgrass process yields higher GHG emissions. This is because most of the process energy for Switchgrass process is generated from GHG emission neutral biomass residue. *49% actual ethanol energy content, energy content in cattle feed by-product reflects chemical energy content, not lifecycle energy displacement. **Energy savings in the refinery due to the higher value of ethanol compared to gasoline.

4. Environmental and safety aspects of combustion technology

This review is aimed to introduce historical background for the sustainability concept development. Special reference is given to the resource depletion and its forecast. In the assessment of global energy, water and environment resources attention is focussed in on the resource consumption and its relevancy to the future demand. In the review of the sustainability concept development special emphasise is devoted to the definition of

sustainability and its relevancy to the historical background of the sustainability idea. The recent assessment of sustainability is reflecting the normative and strategic dimension of sustainability.

Special attention is devoted to the most recent development of the concept of sustainability science. A new field of sustainability science emerging that seeks to understand the fundamental character of interactions between nature and society. Such an understanding must encompass the interaction of global processes with the ecological and so characteristics of particular places and sectors. With a view toward promoting research necessary to achieve such advances, it was proposed an initial set of core questions for sustainability science. The definition of sustainability concept involves an important transformation and extension of the ecologically based concept of physical sustainability to the social and economic context of development. Thus, terms of sustainability cannot exclusively be defined from an environmental point of view or basis of attitudes. Rather, the challenge is to define operational and consistent terms of sustainability from an integrated social, ecological, and economic system perspective. In this respect, the weak and strong sustainability concepts are discussed. In order to introduce measuring of sustainability, the attention is devoted to the definition of respective criteria. There have been a number of attempts to define the criterions for the assessment of the sustainability of the market products. Having those criterions as bases, it was introduced as a specific application in the energy system design. Measuring sustainability is a major issue as well as a driving force of the discussion on sustainability development. Special attention in this review is devoted to the potential sustainable development options. In this respect, a following options are taken into a consideration: prevention of the energy resource depletion with scarcity index control; efficiency assessment; new and renewable energy sources; water pollution mitigation, water desalination technologies environment capacity for combustion products; mitigation of nuclear treat to the environment.

4.1. Sulphur in fuels and its environmental consequences

Coal is formed from the deposition of plant material according to the peat to anthracite series:

Vegetation $\longrightarrow$ Peat
$\longrightarrow$ Lignite (brown coal)
$\longrightarrow$ Sub-bituminous coal
$\longrightarrow$ Bituminous coal $\longrightarrow$ Anthracite

Organic sulphur is bonded within the organic structure of the coal in the same way that sulphur is bonded in simple thio-organics, e.g., thiols. Sulphur contents of coals vary widely, and Table 10 gives some examples.

4.2. Control of SO_2 emissions

Emissions will also, of course, occur from petroleum-based or shale-based fuels, and in heavy consumption, such as in steam raising. There will frequently be a need to control

Table 10
Representative sulphur contents of coals [13]

Source	Rank	Sulphur content (%)
Ayrshire, Scotland	Bituminous	0.6
Lancs./Cheshire, UK	Bituminous	Up to 2.4
S. Wales, UK	Anthracite	Up to 1.5
Victoria, Australia	Lignite	Typically 0.5
Pennsylvania, USA	Anthracite	0.7
Natal, S. Africa	Bituminous	Up to 4.2
Bulgaria	Lignite	2.5

Table 11
Examples of SO_2 control procedures

Type of control	Fuel	Details
Pre-combustion	Fuels from crude oil	Alkali treatment of crude oil to convert thiols RSSR, disulphides; solvent removal of the disulphides
Post-combustion	Coal or fuel oil	Alkali scrubbing of the flue gases with $CaCO_3$/CaO
Combustion	Coal	Limestone, $MgCO_3$ and/or other metallic compounds used to fix the sulphur as sulphates

SO_2 emissions. There are, broadly speaking, three ways of achieving such control:

- *Pre-combustion control*: involves carrying out a degree of desulphurisation of the fuel.
- *Combustion control*: incorporating into the combustion system something capable of trapping SO_2.
- *Post-combustion control*: removing SO_2 from the flue gases before they are discharged into the atmosphere.

Table 11 gives brief details of an example of each.

4.3. The control of NO_x release by combustion processes

Emission of nitrogen oxides is a major topic in fuel technology. It has to be considered even in the total absence of fuel nitrogen if the temperature is high enough for thermal NO_x, as it is in very many industrial applications. The burnt gas from the flame is recirculated in two ways:

- Internally, by baffling and restricting flow of the burnt gas away from the burner, resulting in flame re-entry of part of it.
- Externally, by diverting up to 10% of the flue gas back into the flame.

Some of the available control procedures for particles are summarised in Table 12. Fig. 9 shows the variation of distribution factor with particle size.

Table 12
Particle control techniques

Technique	Principle	Application
Gravity settlement	Natural deposition by gravity of particles from a horizontally flowing gas, collection in hoppers	Removal of coarse particles (>50 μm) from a gas stream, smaller particles removable in principle but require excessive flow distances
Cyclone separator	Tangential entry of a particle-laden gas into a cylindrical or conical enclosure, movement of the particles to the enclosure wall and from there to a receiver	Numerous applications, wide range of particles sizes removable, from 5 to 200 μm, poorer efficiencies of collection for the smaller particles
Fabric filters	Retention of solids by a filter, filter materials include woven cloth, felt and porous membranes	Used in dust removal for over a century
Electrostatic precipitation	Passage of particle-laden gas between electrodes, application of an electric field to the gas, resulting in acquisition of charge by the particles and attraction to an electrode where coalescence occurs, electrical resistivity of the dust an important factor in performance	Particles down to 0.01 μm removable, extensive application to the removal of flyash from pulverised fuel (pf) combustion

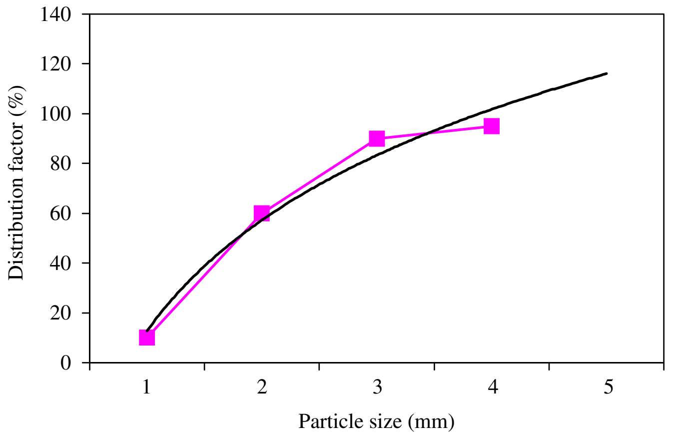

Fig. 9. The variation of distribution factor against particle size for coal undersizes in a classifier. The sizes correspond to mid-point for ranges.

5. Green heat

The ground is as universal as air and solar radiation. Over the past 20 years, as the hunt for natural low-carbon energy sources has intensified, there has been an increased endeavour to investigate and develop both earth and ground water thermal energy storage and usage. Geothermal energy solutions, although well known, are another in our armoury of renewable energy sources that are within our immediate grasp to use and integrate with

an overall energy policy. For high temperature heat storage with temperatures in excess of 50 °C, the particular concerns were:

- Clogging of wells and heat exchangers due to fines and precipitation of minerals.
- Water treatment to avoid operational problems resulting from the precipitation of minerals.
- Corrosion of components in the groundwater system.
- Automatic control of the ground water system.

As consumers in less-developed countries increase their capacity of electricity and green power, developed nations are starting to realise the benefits of using low-grade thermal energy for green heat applications that do not require high-grade electricity. This shift will not only benefit renewable energies that are designed for space conditioning, but also will contribute to the global mix of green power and green heat capacity. Earth energy (also called geothermal or ground source heat pumps or GeoExchange), which transfers absorbed solar heat from the ground into a building for space heating or water heating. The same system can be reversed to reject heat from the interior into the ground, in order to provide cooling. A typical configuration buries polyethylene pipe below the frost line to serve as the head source (or sink), or it can use lake water and aquifers as the heat medium.

An advantage is gained from the necessity to provide filtered fresh air for ventilation purposes by providing every dwelling with a heat recovery mechanical ventilation system. Incorporation of a heating/cooling coil within the air-handling unit for each of the five blocks allows for active summertime cooling (i.e., collecting heat in summer), which along with the use of roof mounted solar panels, helps to provide domestic hot water, produces well tempered and well engineered hybrid low energy scheme at very low-carbon emissions.

6. Effects of urban density

Compact development patterns can reduce infrastructure demands and the need to travel by car. As population density increases, transportation options multiply and dependence areas, per capita fuel consumption is much lower in densely populated areas because people drive so much less. Few roads and commercially viable public transport are the major merits. On the other hand, urban density is a major factor that determines the urban ventilation conditions, as well as the urban temperature. Under given circumstances, an urban area with a high density of buildings can experience poor ventilation and strong heat island effect. In warm-humid regions, these features would lead to a high level of thermal stress of the inhabitants and increased use of energy in air-conditioned buildings.

However, it is also possible that a high-density urban area, obtained by a mixture of high and low buildings, could have better ventilation conditions than an area with lower density but with buildings of the same height. Closely spaced or high-rise buildings are also affected by the use of natural lighting, natural ventilation and solar energy. If not properly planned, energy for electric lighting and mechanical cooling/ventilation may be increased and application of solar energy systems will be greatly limited. Table 13 gives a summary of the positive and negative effects of urban density. All in all, denser city models require more careful design in order to maximise energy efficiency and satisfy other social and development requirements. Low energy design should not be considered in isolation, and in fact, it is a measure, which should work in harmony with other environmental

Table 13
Effects of urban density on city's energy demand

Positive effects	Negative effects
Transport Promote public transport and reduce the need for, and length of, trips by private cars	*Transport* Congestion in urban areas reduces fuel efficiency of vehicles
Infrastructure Reduce street length needed to accommodate a given number of inhabitants Shorten the length of infrastructure facilities such as water supply and sewage lines, reducing the energy needed for pumping	*Vertical transportation* High-rise buildings involve lifts, thus, increasing the need for electricity for the vertical transportation
Thermal performance Multi-story, multiunit buildings could reduce the overall area of the building's envelope and heat loss from the buildings Shading among buildings could reduce solar exposure of buildings during the summer period	*Urban heat island* Heat released and trapped in the urban areas may increase the need for air conditioning The potential for natural lighting is generally reduced in high-density areas, increasing the need for electric lighting and the load on air conditioning to remove the heat resulting from the electric lighting
Energy systems District cooling and heating system, which is usually more energy efficiency, is more feasible as density is higher	*Use of solar energy* Roof and exposed areas for collection of solar energy are limited
Ventilation A desirable flow pattern around buildings may be obtained by proper arrangement of high-rise building blocks	*Ventilation* A concentration of high rise and large buildings may impede the urban ventilation conditions

objectives. Hence, building energy study provides opportunities not only for identifying energy and cost savings, but also for examining the indoor and outdoor environment.

6.1. Energy efficiency and architectural expression

The focus of the world's attention on environmental issues in recent years has stimulated response in many countries, which have led to a closer examination of energy conservation strategies for conventional fossil fuels. Buildings are important consumers of energy and thus important contributors to emissions of greenhouse gases into the global atmosphere. The development and adoption of suitable renewable energy technology in buildings has an important role to play. A review of options indicates benefits and some problems [14]. There are two key elements to the fulfilling of renewable energy technology potential within the field of building design: first the installation of appropriate skills and attitudes in building design professionals and second the provision of the opportunity for such people to demonstrate their skills. This second element may only be created when the population at large and clients commissioning building design in particular, become more aware of what can be achieved and what resources are required. Terms like passive cooling or passive solar use mean that the cooling of a building or the exploitation of the energy of the

sun is achieved not by machines but by the building's particular morphological organisation. Hence, the passive approach to themes of energy savings is essentially based on the morphological articulations of the constructions. Passive solar design, in particular, can realise significant energy and cost savings. For a design to be successful, it is crucial for the designer to have a good understanding of the use of the building. Few of the buildings had performed as expected by their designers. To be more precise, their performance had been compromised by a variety of influences related to their design, construction and operation. However, there is no doubt that the passive energy approach is certainly the one that, being supported by the material shape of the buildings has a direct influence on architectural language and most greatly influences architectural expressiveness [15]. Furthermore, form is a main tool in architectural expression. To give form to the material things that one produces is an ineluctable necessity. In architecture, form, in fact, summarises and gives concreteness to its every value in terms of economy, aesthetics, functionality and, consequently, energy efficiency [16]. The target is to enrich the expressive message with forms producing an advantage energywise. Hence, form, in its geometric and material sense, conditions the energy efficiency of a building in its interaction with the environment. It is, then, very hard to extract and separate the parameters and the elements relative to this efficiency from the expressive unit to which they belong. By analysing energy issues and strategies by means of the designs, of which they are an integral part, one will, more easily, focus the attention on the relationship between these themes, their specific context and their architectural expressiveness. Many concrete examples and a whole literature have recently grown up around these subjects and the wisdom of forms and expedients that belong to millennia-old traditions has been rediscovered. Such a revisiting, however, is only, or most especially, conceptual, since it must be filtered through today's technology and needs; both being almost irreconcilable with those of the past. Two among the historical concepts are of special importance. One is rooted in the effort to establish rational and friendly strategic relations with the physical environment, while the other recognises the interactions between the psyche and physical perceptions in the creation of the feeling of comfort. The former, which may be defined as an alliance with the environment deals with the physical parameters involving a mixture of natural and artificial ingredients such as soil and vegetation, urban fabrics and pollution [17]. The most dominant outside parameter is, of course, the sun's irradiation, our planet's primary energy source. All these elements can be measured in physical terms and are therefore the subject of science. Within the second concept, however, one considers the emotional and intellectual energies, which are the prime inexhaustible source of renewable power [18]. In this case, cultural parameters, which are not exactly measurable, are involved. However, they represent the very essence of the architectural quality. Objective scientific measurement parameters tell us very little about the emotional way of perceiving, which influences the messages of human are physical sensorial organs. The perceptual reality arises from a multitude of sensorial components; visual, thermal, acoustic, olfactory and kinaesthetics. It can, also, arise from the organisational quality of the space in which different parameters come together, like the sense of order or of serenity. Likewise, practical evaluations, such as usefulness, can be involved too. The evaluation is a wholly subjective matter, but can be shared by a set of experiencing persons [19]. Therefore, these cultural parameters could be different in different contexts in spite of the inexorable levelling on a planetwide scale. However, the parameters change in the anthropological sense, not only with the cultural environment, but also in relation to

function. The scientifically measurable parameters can, thus, have their meanings very profoundly altered by the non-measurable, but describable, cultural parameters.

However, the low energy target also means to eliminate any excess in the quantities of material and in the manufacturing process necessary for the construction of our built environment. This claims for a more sober, elegant and essential expression, which is not jeopardising at all, but instead enhancing, the richness and preciousness of architecture, while contributing to a better environment from an aesthetic viewpoint [20]. Arguably, the most successful designs were in fact the simplest. Paying attention to orientation, plan and form can have far greater impact on energy performance than opting for elaborate solutions [21]. However, a design strategy can fail when those responsible for specifying materials for example, do not implement the passive solar strategy correctly. Similarly, cost-cutting exercises can seriously upset the effectiveness of a design strategy. Therefore, it is imperative that a designer fully informs key personnel, such as the quantity surveyor and client, about their design and be prepared to defend it. Therefore, the designer should have an adequate understanding of how the occupants or processes, such as ventilation, would function within the building. Thinking through such processes in isolation without reference to others can lead to conflicting strategies, which can have a detrimental impact upon performance. Likewise, if the design intent of the building is not communicated to its occupants, there is a risk that they will use it inappropriately, thus, compromising its performance. Hence, the designer should communicate in simple terms the actions expected of the occupant to control the building. For example, occupants should be well informed about how to guard against summer overheating. If the designer opted for a simple, seasonally adjusted control; say, insulated sliding doors were to be used between the mass wall and the internal space. The lesson here is that designers must be prepared to defend their design such that others appreciate the importance and interrelationship of each component. A strategy will only work if each individual component is considered as part of the bigger picture. Failure to implement a component or incorrect installation, for example, can lead to failure of the strategy and consequently, in some instances, the building may not liked by its occupants due to its poor performance.

6.2. *Energy efficiency*

Energy efficiency is the most cost-effective way of cutting carbon dioxide emissions and improvements to households and businesses. It can also have many other additional social, economic and health benefits, such as warmer and healthier homes, lower fuel bills and company running costs and, indirectly, jobs. Britain wastes 20% of its fossil fuel and electricity use. This implies that it would be cost-effective to cut £10 billion a year off the collective fuel bill and reduce CO_2 emissions by some 120 million tones. Yet, due to lack of good information and advice on energy saving, along with the capital to finance energy efficiency improvements, this huge potential for reducing energy demand is not being realised. Traditionally, energy utilities have been essentially fuel providers and the industry has pursued profits from increased volume of sales. Institutional and market arrangements have favoured energy consumption rather than conservation. However, energy is at the centre of the sustainable development paradigm as few activities affect the environment as much as the continually increasing use of energy. Most of the used energy depends on finite resources, such as coal, oil, gas and uranium. In addition, more than three-quarters of the world's consumption of these fuels is used, often inefficiently, by only one-quarter of the

world's population. Without even addressing these inequities or the precious, finite nature of these resources, the scale of environmental damage will force the reduction of the usage of these fuels long before they run out.

Throughout the energy generation process, there are impacts on the environment on local, national and international levels, from opencast mining and oil exploration to emissions of the potent greenhouse gas carbon dioxide in ever increasing concentration. Recently, the world's leading climate scientists reached an agreement that human activities, such as burning fossil fuels for energy and transport, are causing the world's temperature to rise. The Intergovernmental Panel on Climate Change has concluded that "the balance of evidence suggests a discernible human influence on global climate". It predicts a rate of warming greater than any one seen in the last 10,000 years, in other words, throughout human history. The exact impact of climate change is difficult to predict and will vary regionally. It could, however, include sea level rise, disrupted agriculture and food supplies and the possibility of more freak weather events such as hurricanes and droughts. Indeed, people already are waking up to the financial and social, as well as the environmental, risks of unsustainable energy generation methods that represent the costs of the impacts of climate change, acid rain and oil spills. The insurance industry, for example, concerned about the billion dollar costs of hurricanes and floods, has joined sides with environmentalists to lobby for greenhouse gas emissions reduction. "Friends of the earth" is campaigning for a more sustainable energy policy, guided by the principle of environmental protection and with the objectives of sound natural resource management and long-term energy security. The key priorities of such an energy policy must be to reduce fossil fuel use, move away from nuclear power, improve the efficiency with which energy is used and increase the amount of energy obtainable from sustainable, renewable sources. Efficient energy use has never been more crucial than it is today, particularly with the prospect of the imminent introduction of the climate change levy (CCL). Establishing an energy use action plan is the essential foundation to the elimination of energy waste. A logical starting point is to carry out an energy audit that enables the assessment of the energy use and determine what actions to take. The actions are best categorised by splitting measures into the following three general groups:

(1) *High priority/low cost*: These are normally measures, which require minimal investment and can be implemented quickly. The followings are some examples of such measures:
   - Good housekeeping, monitoring energy use and targeting waste-fuel practices.
   - Adjusting controls to match requirements.
   - Improved greenhouse space utilisation.
   - Small capital item time switches, thermostats, etc.
   - Carrying out minor maintenance and repairs.
   - Staff education and training.
   - Ensuring that energy is being purchased through the most suitable tariff or contract arrangements.

(2) *Medium priority/medium cost*: Measures, which, although involve little or no design, involve greater expenditure and can take longer to implement. Examples of such measures are listed below:
   - New or replacement controls.
   - Greenhouse component alteration, e.g., insulation, sealing glass joints, etc.
   - Alternative equipment components, e.g., energy efficient lamps in light fittings, etc.

(3) *Long-term/high cost*: These measures require detailed study and design. They can be best represented by the followings:
- Replacing or upgrading of plant and equipment.
- Fundamental redesign of systems, e.g., CHP installations.
  This process can often be a complex experience and therefore the most cost-effective approach is to employ an energy specialist to help.

6.3. Policy recommendations for a sustainable energy future

Sustainability is regarded as a major consideration for both urban and rural development. People have been exploiting the natural resources with no consideration to the effects, both short-term (environmental) and long-term (resources crunch). It is also felt that knowledge and technology have not been used effectively in utilising energy resources. Energy is the vital input for economic and social development of any country. Its sustainability is an important factor to be considered. The urban areas depend, to a large extent, on commercial energy sources. The rural areas use non-commercial sources like firewood and agricultural wastes. With the present day trends for improving the quality of life and sustenance of mankind, environmental issues are considered highly important. In this context, the term energy loss has no significant technical meaning. Instead, the exergy loss has to be considered, as destruction of exergy is possible. Hence, exergy loss minimisation will help in sustainability. In the process of developing, there are two options to manage energy resources: (1) end use matching/demand side management, which focuses on the utilities. The mode of obtaining this is decided based on economic terms. It is, therefore, a quantitative approach. (2) Supply side management, which focuses on the renewable energy resource and methods of utilising it. This is decided based on thermodynamic consideration having the resource-user temperature or exergy destruction as the objective criteria. It is, therefore, a qualitative approach. The two options are explained schematically in Fig. 10. The exergy-based energy, developed with supply side perspective is shown in Fig. 11.

The following policy measures had been identified:

- Clear environmental and social objectives for energy market liberalisation, including a commitment to energy efficiency and renewables.
- Economic, institutional and regulatory frameworks, which encourage the transition to total energy services.
- Economic measures to encourage utility investment in energy efficiency (e.g., levies on fuel bills).
- Incentives for demand side management, including grants for low-income households, expert advice and training, standards for appliances and buildings and tax incentives.
- Research and development funding for renewable energy technologies not yet commercially viable.
- Continued institutional support for new renewables (such as standard cost-reflective payments and obligation on utilities to buy).
- Ecological tax reform to internalise external environmental and social costs within energy prices.
- Planning for sensitive development and public acceptability for renewable energy.

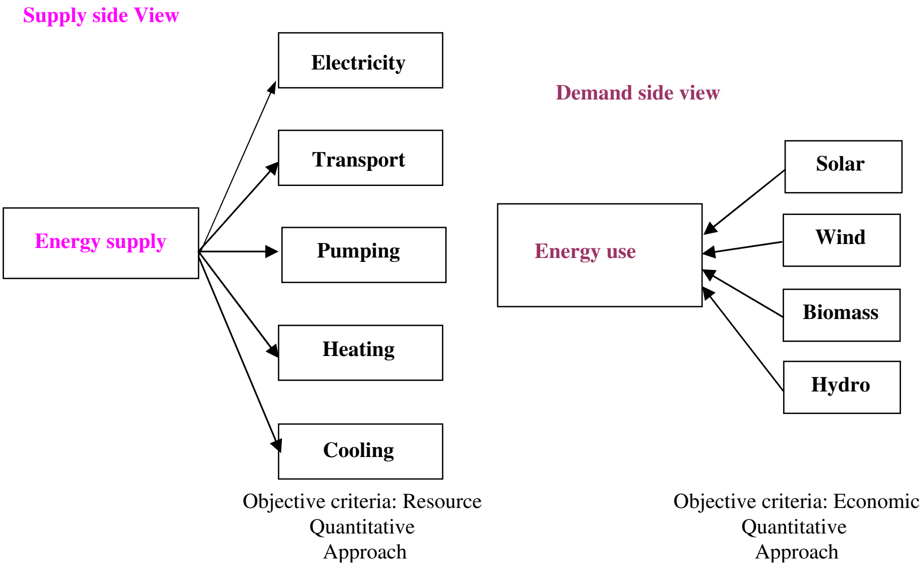

Fig. 10. Supply side and demand side management approach for energy.

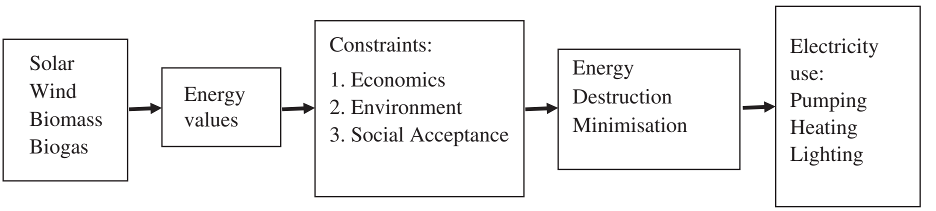

Fig. 11. Exergy-based optimal energy model.

Energy resources are needed for societal development. Their sustainable development requires a supply of energy resources that are sustainably available at a reasonable cost and can cause no negative societal impacts. Energy resources such as fossil fuels are finite and lack sustainability, while renewable energy sources are sustainable over a relatively longer term. Environmental concerns are also a major factor in sustainable development, as activities, which degrade the environment, are not sustainable. Hence, as much as environmental impact is associated with energy, sustainable development requires the use of energy resources, which cause as little environmental impact as possible. One way to reduce the resource depletion associated with cycling is to reduce the losses that accompany the transfer of exergy to consume resources by increasing the efficiency of exergy transfer between resources, i.e., increasing the fraction of exergy removed from one resource that is transferred to another [22].

As explained above, exergy efficiency may be thought of as a more accurate measure of energy efficiency that accounts for quantity and quality aspects of energy flows. Improved exergy efficiency leads to reduced exergy losses. Most efficiency improvements produce

Table 14
Qualities of various energy sources

Source	Energy (J)	Exergy (J)	CQF
Water at 80 °C	100	16	0.16
Steam at 120 °C	100	24	0.24
Natural gas	100	99	0.99
Electricity/work	100	100	1.00

direct environmental benefits in two ways. First, operating energy input requirements are reduced per unit output, and pollutants generated are correspondingly reduced. Second, consideration of the entire life cycle for energy resources and technologies suggests that improved efficiency reduces environmental impact during most stages of the life cycle. Quite often, the main concept of sustainability, which often inspires local and national authorities to incorporate environmental consideration into setting up energy programmes have different meanings in different contexts though it usually embodies a long-term perspective. Future energy systems will largely be shaped by broad and powerful trends that have their roots in basic human needs. Combined with increasing world population, the need will become more apparent for successful implementation of sustainable development.

Heat has a lower exergy, or quality of energy, compared with work. Therefore, heat cannot be converted into work by 100% efficiency. Some examples of the difference between energy and exergy are shown in Table 14.

The terms used in Table 14 have the following meanings:

$$\text{Carnot quality factor (CQF)} = \left(\frac{1 - T_o}{T_s}\right), \tag{5}$$

$$\text{Exergy} = \text{energy (transferred)} \times \text{CQF}, \tag{6}$$

where T_o is the environment temperature (K) and T_s is the temperature of the stream (K).

Various parameters are essential to achieving sustainable development in a society. Some of them are as follows:

- public awareness
- information
- environmental education and training
- innovative energy strategies
- renewable energy sources and cleaner technologies
- financing
- monitoring and evaluation tools

The development of a renewable energy in a country depends on many factors. Those important to success are listed below:

(1) *Motivation of the population*: The population should be motivated towards awareness of high environmental issues, rational use of energy in order to reduce cost. Subsidy

programme should be implemented as incentives to install renewable energy plants. In addition, image campaigns to raise awareness of renewable technology.

(2) *Technical product development*: To achieve technical development of renewable energy technologies the following should be addressed:
- increasing the longevity and reliability of renewable technology,
- adapting renewable technology to household technology (hot water supply),
- integration of renewable technology in heating technology,
- integration of renewable technology in architecture, e.g., in the roof or façade,
- development of new applications, e.g., solar cooling,
- cost reduction.

(3) *Distribution and sales*: Commercialisation of renewable energy technology requires:
- inclusion of renewable technology in the product range of heating trades at all levels of the distribution process (wholesale, retail),
- building distribution nets for renewable technology,
- training of personnel in distribution and sales,
- training of field sales force.

(4) *Consumer consultation and installation*: To encourage all sectors of the population to participate in adoption of renewable energy technologies, the following has to be realised:
- acceptance by craftspeople, marketing by them,
- technical training of craftspeople, initial and follow-up training programmes,
- sales training for craftspeople,
- information material to be made available to craftspeople for consumer consultation.

(5) *Projecting and planning*: Successful application of renewable technologies also require:
- acceptance by decision makers in the building sector (architects, house technology planners, etc.),
- integration of renewable technology in training,
- demonstration projects/architecture competitions,
- renewable energy project developers should prepare to participate in the carbon market by:
  - ensuring that renewable energy projects comply with Kyoto Protocol requirements,
  - quantifying the expected avoided emissions,
  - registering the project with the required offices,
  - contractually allocating the right to this revenue stream.
- Other ecological measures employed on the development include:
  - simplified building details,
  - reduced number of materials,
  - materials that can be recycled or reused,
  - materials easily maintained and repaired,
  - materials that do not have a bad influence on the indoor climate (i.e., non-toxic),
  - local cleaning of grey water,
  - collecting and use of rainwater for outdoor purposes and park elements,
  - building volumes designed to give maximum access to neighbouring park areas,
  - all apartments have visual access to both backyard and park.

(6) *Energy saving measures*: The following energy saving measures should also be considered:
- building integrated solar PV system,
- day-lighting,
- ecological insulation materials,
- natural/hybrid ventilation,
- passive cooling,
- passive solar heating,
- solar heating of domestic hot water,
- utilisation of rainwater for flushing.

Improving access for rural and urban low-income areas in developing countries must be through energy efficiency and renewable energies. Sustainable energy is a prerequisite for development. Energy-based living standards in developing countries, however, are clearly below standards in developed countries. Low levels of access to affordable and environmentally sound energy in both rural and urban low-income areas are therefore a predominant issue in developing countries. In recent years, many programmes for development aid or technical assistance have been focusing on improving access to sustainable energy, many of them with impressive results.

Apart from success stories, however, experience also shows that positive appraisals of many projects evaporate after completion and vanishing of the implementation expert team. Altogether, the diffusion of sustainable technologies such as energy efficiency and renewable energies for cooking, heating, lighting, electrical appliances and building insulation in developing countries has been slow.

Energy efficiency and renewable energy programmes could be more sustainable and pilot studies more effective and pulse releasing if the entire policy and implementation process was considered and redesigned from the outset. New financing and implementation processes are needed which allow reallocating financial resources and thus enabling countries themselves to achieve a sustainable energy infrastructure. The links between the energy policy framework, financing and implementation of renewable energy and energy efficiency projects have to be strengthened, and capacity building efforts are required.

7. Conclusions

There is strong scientific evidence that the average temperature of the earth's surface is rising. This is a result of the increased concentration of carbon dioxide and other GHGs in the atmosphere as released by burning fossil fuels. This global warming will eventually lead to substantial changes in the world's climate, which will, in turn, have a major impact on human life and the built environment. Therefore, effort has to be made to reduce fossil energy use and to promote green energies, particularly in the building sector. Energy use reductions can be achieved by minimising the energy demand, by rational energy use, by recovering heat and the use of more green energies. This study was a step towards achieving that goal. The adoption of green or sustainable approaches to the way in which society is run is seen as an important strategy in finding a solution to the energy problem. The key factors to reducing and controlling CO_2, which is the major contributor to global warming, are the use of alternative approaches to energy generation and the exploration of

how these alternatives are used today and may be used in the future as green energy sources. Even with modest assumptions about the availability of land, comprehensive fuel-wood farming programmes offer significant energy, economic and environmental benefits. These benefits would be dispersed in rural areas where they are greatly needed and can serve as linkages for further rural economic development. The nations as a whole would benefit from savings in foreign exchange, improved energy security, and socio-economic improvements. With a nine-fold increase in forest-plantation cover, a nation's resource base would be greatly improved. The international community would benefit from pollution reduction, climate mitigation, and the increased trading opportunities that arise from new income sources. The non-technical issues, which have recently gained attention, include:

(1) Environmental and ecological factors, e.g., carbon sequestration, reforestation and revegetation.
(2) Renewables as a CO_2 neutral replacement for fossil fuels.
(3) Greater recognition of the importance of renewable energy, particularly modern biomass energy carriers, at the policy and planning levels.
(4) Greater recognition of the difficulties of gathering good and reliable renewable energy data, and efforts to improve it.
(5) Studies on the detrimental health efforts of biomass energy particularly from traditional energy users.

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